A Negative-Grid Triode Oscillator and Amplifier for Ultra-High Frequencies *

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THE author describes three negative-grid triodes of unusual design which operate both as oscillators and as amplifiers at ultra-high frequencies. The power output of the smallest tube as an oscillator at 1500 megacycles is 2 watts, and is still capable of an output of 1 watt at 1700 megacycles with an oscillation limit of 1870 megacycles corresponding to a wave-length of 16 centimeters. This tube also offers possibilities as an amplifier at frequencies as high as 1000 megacycles. Such capabilities of the negative-grid triode are notable since this device has appeared to lag behind the magnetron as an *oscillator* at frequencies of above roughly 500 megacycles, while the only successful power *amplifiers* which have been described for frequencies of the order of 300 megacycles are multi-element tubes.

Fig. 1—Experimental double-lead tubes.

The triode as used at radio frequencies differs from the multi-element tube chiefly in the manner in which interaction is prevented between the input and output circuits. This is obviously a circuit limitation, as contrasted with the electron transit time limitation which has received so much attention. The greatest opportunity for improvement seems to be in the direction of improved circuit design. The tubes described in this paper were developed from this point of view.

Sample tubes are shown in Fig. 1. They differ from previous designs

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primarily in the lead arrangement. From the section view of one of these tubes, shown in Fig. 2, it will be observed that the grid and plate elements are supported by wires which in effect go straight through the

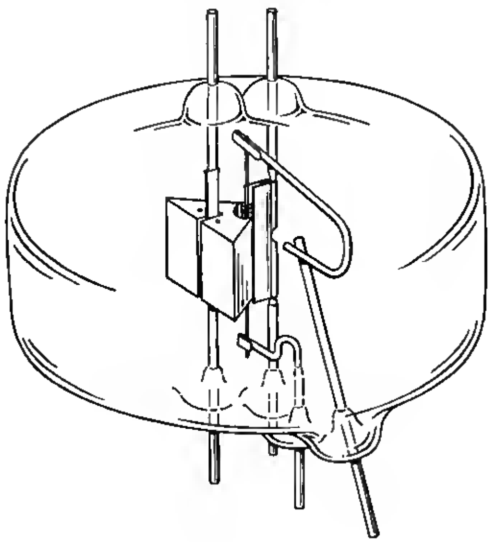

Fig. 2—Section view of one of the double-lead tubes.

tube envelope providing two independent leads to each of these elements. The filament leads are at one end only and one of these leads is extremely short. This unusual lead arrangement possesses a number of unique advantages.

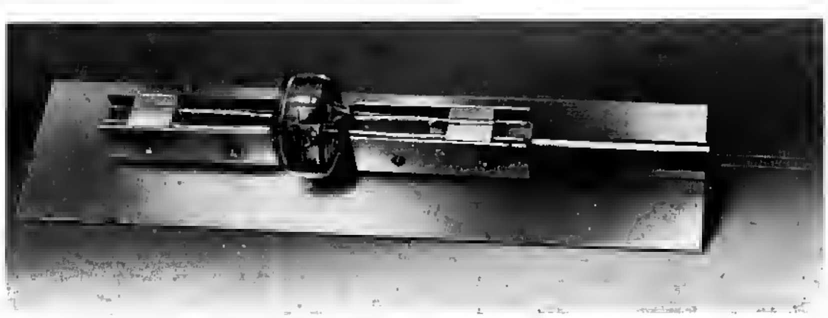

Fig. 3—Typical oscillator circuit.

A typical oscillator circuit is shown in Fig. 3. Here the tube is mounted at the center of a half-wave Lecher system. This arrangement provides a higher natural frequency circuit than that of the

quarter-wave Lecher system formed by removing one set of leads. Since only half of the total charging current to the inter-electrode capacitances flows through each set of leads, the losses due to the lead resistances are also reduced. In the tubes under discussion the electron transit time limitation has been met by the use of extremely small inter-electrode spacings so that full advantage may be taken of the increased frequency range.

For the purpose of confirming the above conclusion, efficiency curves have been obtained on the large size tube, as shown in Fig. 1, when operated both single- and double-ended. The results are shown in Fig. 4. It will be observed that the efficiencies for double-ended operation are always higher than for the single-ended case over the range covered by the experimental data. In fact, usable outputs are obtained at frequencies well beyond the point where the single-ended tube fails to operate. The ratio of the cut-off frequencies for the two tubes happens to be 1.23 for the particular conditions under which these data were obtained.

Output and efficiency curves for the large size tube are shown in Fig. 5. The values of 60 watts at 300 megacycles and 40 watts at 400 megacycles compare quite favorably with outputs reported from radiation-cooled magnetrons. When the problems of modulation and the complications of the magnetron's magnetic field are considered, the advantages of the negative-grid triode become more apparent. The improvement in power output made possible by this departure in design is illustrated by the comparison plot shown in Fig. 6.

The double-lead arrangement is also responsible for an increase in the upper frequency limit at which stable operation as an *amplifier* may be secured.

The primary cause for instability of the triode amplifier is the interaction between the input and output circuits which results from the admittance coupling between these circuits provided by the grid-plate capacitance. A second source of coupling is that caused by common impedances in the two circuits in the nature of the self and mutual inductance of the tube leads. At moderately high frequencies this latter coupling is usually of negligible importance. Stable operation is thus possible when suitable means are provided to compensate or "neutralize" the admittance coupling. At ultra-high frequencies lead-impedance coupling can no longer be neglected. It may, of course, be minimized by the use of short leads. The ultimate solution is to provide independent leads for the input, output and admittance neutralizing circuits. The double-lead tube is an attempt to fulfill these conditions. It will be observed that the only common impedance

remaining is that caused by one filament lead and that this lead is extremely short.

In the present investigation the method of neutralizing admittance coupling has been that disclosed by H. W. Nichols in U. S. Patent

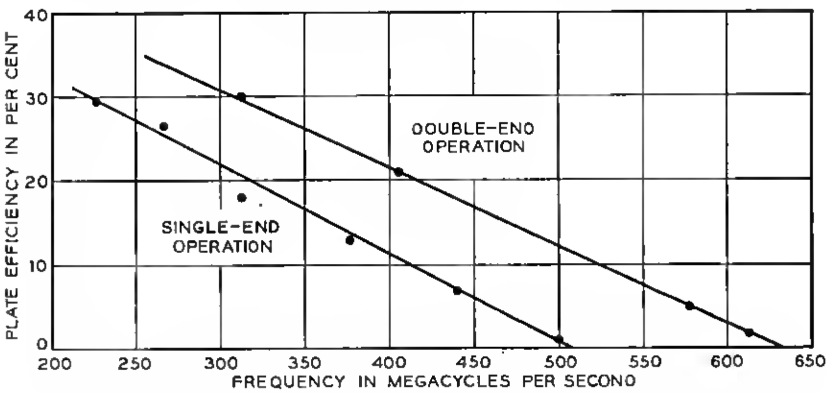

Fig. 4—Comparison plot of output efficiency for the large tube when operated single-ended and double-ended.

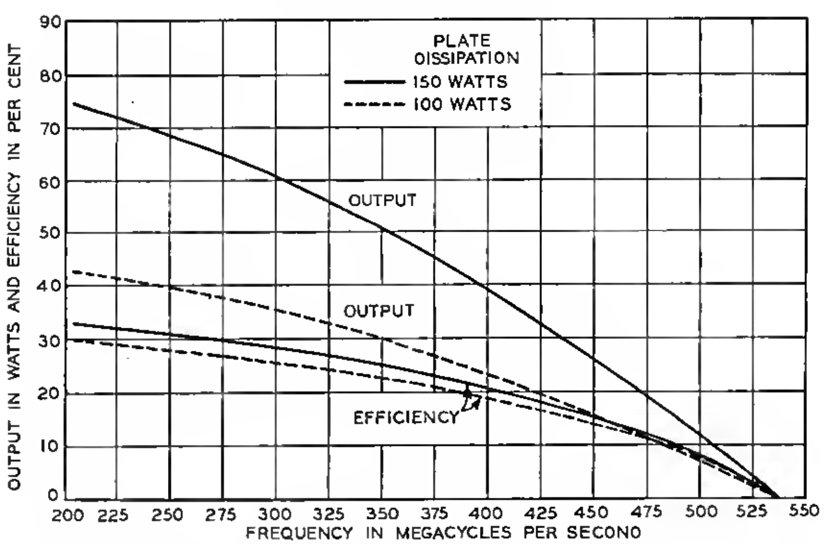

Fig. 5—Output and efficiency as a function of frequency for the large tube.

1,325,879 and involves the resonating of the offending admittances at the desired operating frequency so that the resulting parallel admittance is reduced to a very low value. This takes the form of an inductance connected between the grid and plate of the tube and adjusted

to resonate with the grid-plate capacitance. For ease of adjustment a somewhat lower fixed inductance may be used and tuned by the adjustment of a small variable condenser in parallel. This form of neutralization is commonly referred to as "coil" neutralization. At ultra-high frequencies where unavoidable inductances are already present in the form of lead inductances, this "coil" scheme possesses

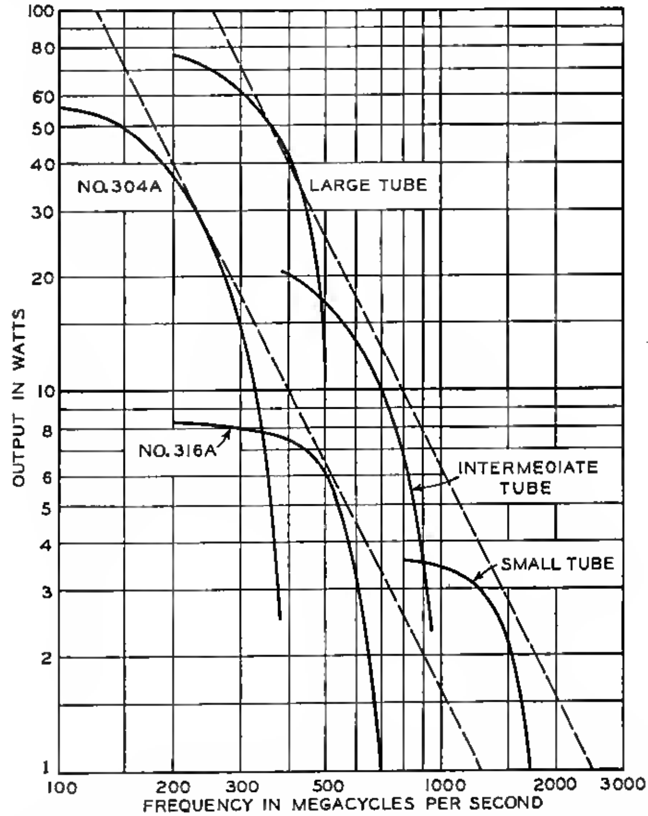

Fig. 6—Comparison plot of the outputs of the double-lead tubes and of commercially available tubes.

outstanding advantages over the more usual "capacitance" schemes. These advantages become even more pronounced with the availability of the double-lead tube.

Verifying this analysis, a "coil-neutralized" two-stage amplifier using two of the largest size tubes was found to yield an output of 60 watts at 144 megacycles for Class B operation. Stability, distortion, and band width were quite comparable to the results obtained on a

pentode of similar rating. A four-stage amplifier employing the intermediate tube gave comparable results and although experimental data are not yet available, it seems reasonable to assume that the small size tube will permit of stable operation as an amplifier at frequencies as high as 1000 megacycles.

The double-lead tube is therefore seen to possess a number of distinct advantages, both as oscillator and as amplifier, in the frequency range from 100 megacycles to 1000 megacycles. While the ultimate limit to which such developments may be pushed is still a matter of conjure it seems safe to predict that the triode will be able to meet the demands of the circuit designer at least for some time to come.